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13. ABSTRACT (Maximum 200 words)

This report reviews the demonstration of visible and Mid-Wave Infrared (MWIR) imaging spectrometers at a White sands Missile Range (WSMR) launch. These imaging spectrometers are non-scanning, high speed imaging spectrometer capable of simultaneously recording spatial and spectral data from a rapidly varying target scene. High-speed spectral imaging was demonstrated by collecting spectral and spatial snapshots of a missile launch at WSMR. The instruments are based on computed tomography concepts. The infrared instrument operates in a 3.0 to 4.6 μm with resolution of 0.2. Raw images were recorded at a video frame rate of 30 fps using a 160 x 120 InSb focal plane array. A reconstruction of a simple 819 K blackbody object is presented as proof of concept. A visible spectrometer was also used but only for proof of concept of this technology, operates from 420 to 740 nm with resolution of 10 nm at 15 fps using a 1024 by 1024 focal plane. All data collected was given to the sponsor and not discussed or shown herein.

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CITIS Demonstration

Abstract

This report reviews the demonstration of visible and Mid-Wave Infrared (MWIR) imaging spectrometers at a White sands Missile Range (WSMR) launch. These imaging spectrometers are non-scanning, high speed imaging spectrometer capable of simultaneously recording spatial and spectral data from a rapidly varying target scene. High-speed spectral imaging was demonstrated by collecting spectral and spatial snapshots of a missile launch at WSMR. The instruments are based on computed tomography concepts. The infrared instrument operates in a 3.0 to 4.6 μm with resolution of 0.2. Raw images were recorded at a video frame rate of 30 fps using a 160 x 120 InSb focal plane array. A reconstruction of a simple 819 K blackbody object is presented as proof of concept. A visible spectrometer was also used but only for proof of concept of this technology, operates from 420 to 740 nm with resolution of 10 nm at 15 fps using a 1024 by 1024 focal plane. All data collected was given to the sponsor and not discussed or shown herein.

OVERVIEW OF THE CTIS INSTRUMENT

The driving concept behind the development of the computed tomographic imaging spectrometer (CTIS) is the reconstruction of a 3D object from 2D projections. The objective here is to record 2D projections of the x, y, λ object cube. If sufficient projections are recorded, then the original object cube can be reconstructed. These projections are shown schematically in Fig. 1. A two-dimensional array records these many "shadows," and reconstruction of the (x, y, λ) object is accomplished via inversion math methods.

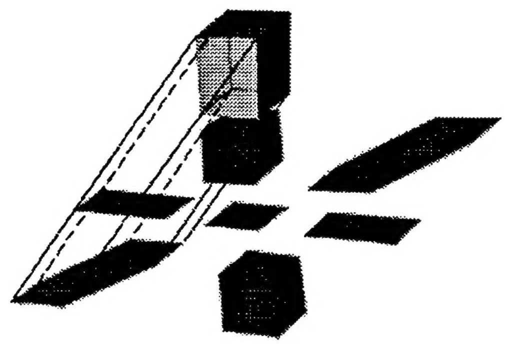

Fig. 1. Projections of the object cube. Spectral information along the vertical axis of the object cube is projected along the radial coordinate of the focal plane and multiplexed with spatial information.

Description of the Instrument

The spectrometer consists of three optical-element groups: an objective lens, a collimator lens, and a re-imaging lens both the visible and infrared instruments are similar in optical layout.

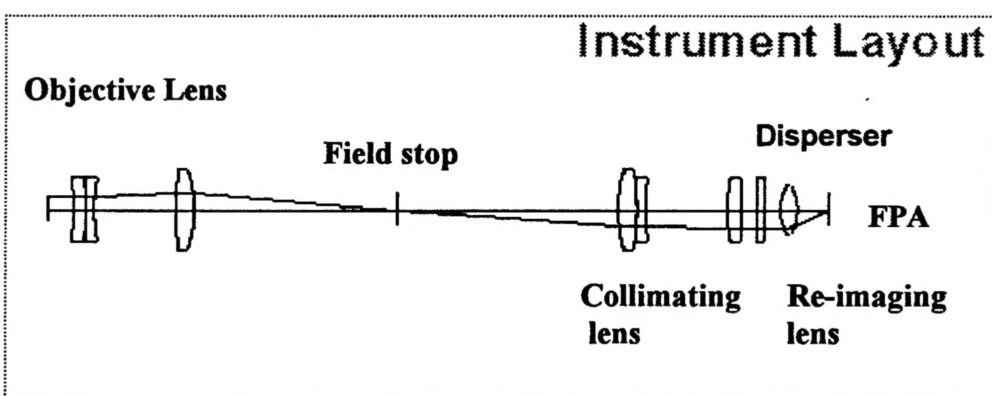

Fig. 2. Optical schematic of the CTIS

The use of AR coated lenses for the 3 – 5 μm band throughout the optical train greatly enhances the performance of the instrument. The Computer Generated Hologram (CGH) disperser is located in collimated space between the collimator lens and the re-imaging

lens. A 250 mm focal length objective lens focuses the target onto a 5mm square field stop, thus a 20 milliradian field of view. The field stop is appropriately minified and dispersed on to the InSb FPA by the combination of a 250 mm collimating lens, GaAs binary diffraction grating and 50 mm re-imaging lens. The FPA in the prototype system shown in Fig 3. is a 160 x 120 InSb array with 50 μm pitch and 30% fill factor operating at 30 frames per second and 5 msec. integration time. The Stirling cycle cooler built into the camera enhances portability of the system. The 5 mm square field stop maps to an 20 x 20 pixel area on the FPA. Only the four first orders are used in reconstructions. Datacubes up to 11 x 11 x 8 (x, y, λ) have been reconstructed, requiring approximately 30 ms per reconstruction on a portable computer (PII-333). The visible instrument uses a zoom lens objective with a 5 mm square field stop have a 20 milliradian field of view. The collimator lens (efl = 210 mm) and re-imaging lens (efl = 28 mm) makes an 80 x 80 pixel area with 32 spectral channels from 420 to 740 nm.

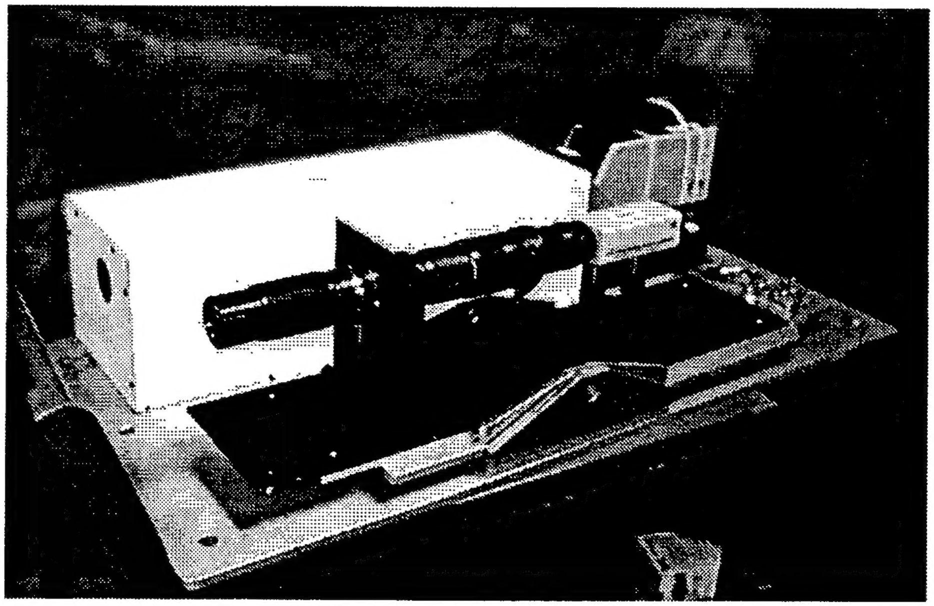

Fig 3. Prototype Visible CTIS (showing optical train) and a MWIR CTIS inside the white enclosure.

While the IR lenses were purchased from vendors, the two-dimensional binary disperser (which is actually a diffractive phase grating) shown in Figure 4 was custom fabricated at the Optical Sciences Center in GaAs. The phase grating has a period of 90 μm in both the x and y directions was chosen in combination with the field stop size, the collimating lens focal length and the re-imaging lens focal length to place the zero and first diffraction orders with in the focal plane. The physical depth of the grating was initially chosen to be 0.7 μm. The depth was subsequently fine tuned by trial and error to 1.1 μm to give reasonable irradiance uniformity across the focal plane.

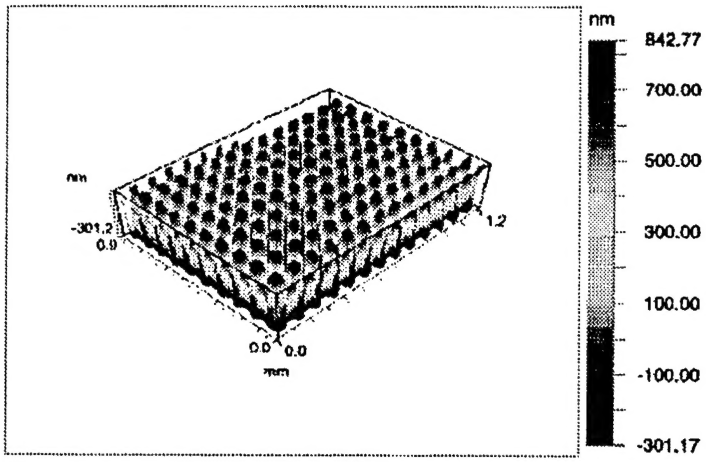

Fig. 4. Wyko interferometer surface profile of the 2-D binary phase grating fabricated using Reactive Ion Etching at the Optical Sciences Center by Michael Descour and Daniel Simon.

CALIBRATION

The visible system is calibrated using a fiber optics and an ISA Instruments grating monochromator. The resolution of the instrument is limited by the calibration process to be 10 nm. Each resolution element is calibrated spectrally over the visible region (80 x 80 x 32).

The MWIR CTIS calibration process was accomplished using a 973 K blackbody and the grating monochromator. The output port of a 973 K blackbody is coupled directly into the same computer-controlled monochromator with a 4-μm blazed grating. The monochromator allows selection of spectral bands as narrow as 0.1 μm. Presently, the output of the monochromator must be collimated by a telescope, then imaged onto the field stop using the MWIR CITIS objective lens. The exit slit of the monochromator is stopped down with an opaque aperture.

A fold mirror is used to position the calibration spot in the field stop so that it exactly fills four (50 μm) pixels on the FPA to prevent oversampling. The monochromator is then scanned through wavelengths and a calibration image is acquired at each spectral band. Since the instrument is essentially shift invariant over each wavelength, the calibration images may be software-shifted to fill the field stop. There is currently no allowance for absorption over the path difference external to the objective, but absorption over such a short path should not be significant outside of the CO_2 absorption band from 4.2 to 4.4 μm. There is also no normalization of the calibration images by the irradiance of the incident light.

Field Tests

The field tests were conducted at WSMR on KTM tracking mount. A photograph of the instrument mounted on the tracker is shown in Figure 5. The field of view of the instruments was within the tracking accuracy of the KTM tracker. However, there was some concern about keeping the target within the instruments' view.

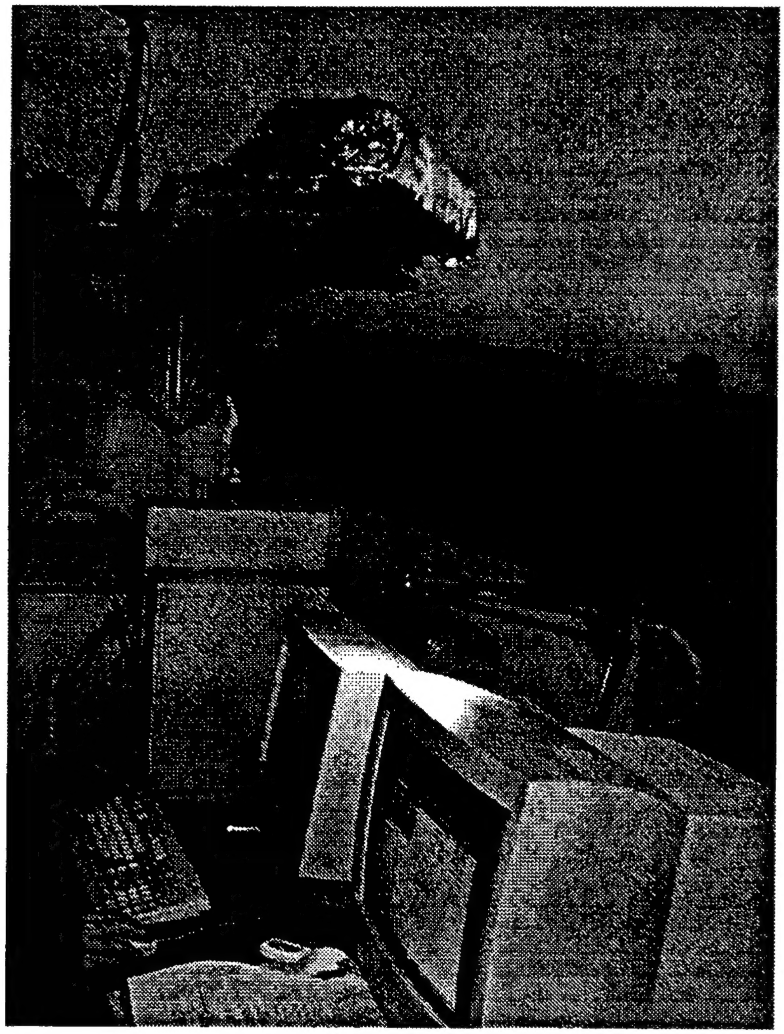

Figure 5. CTIS system on the KTM tracker at WSMR.

The calibration data on a 819 K blackbody in the MWIR is shown in Figure 6. The Blackbody was at a range of 450 feet and the spectral radiance shows a dip in the 4.28 μm region due to the CO_2 absorption. Since the sensor's resolution bands are wider than the CO_2 line, the dip doesn't drop to zero as expected in Figure 6a. On the right side of Figure 6, the spectral images are shown at different wavelengths. Again the 4.25 μm image is washed out due to the carbon dioxide absorption.

Top

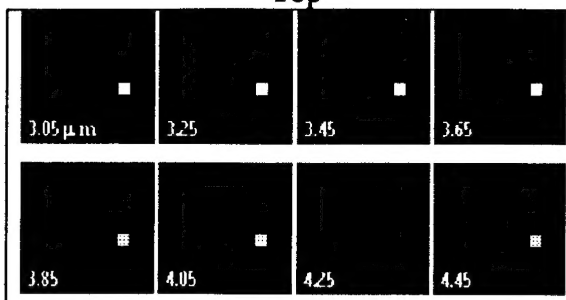

Figure 6a. MWIR spectral images of a 819 K blackbody.

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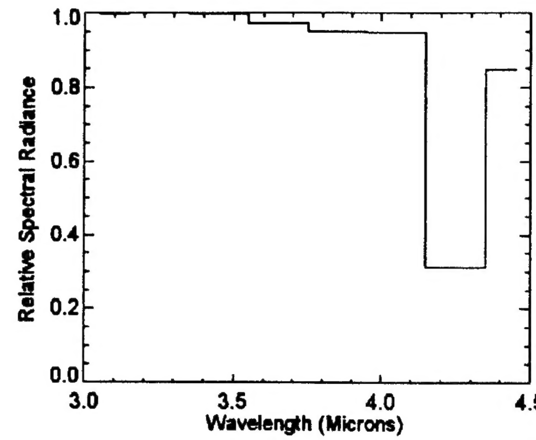

Figure 6b. MWIR CTIS looking at an 819 K blackbody 450 feet. Dip at 4.25 is due to CO_2. Bright center pixel.

CONCLUSION

We have demonstrated a high speed snapshot imaging spectrometer prototype operating in the MWIR as well as the visible in a field deployable portable setup. The instrument is currently undergoing modifications for increased spatial-spectral resolution. Future work includes design of a more efficient disperser and installation of a larger format, variable integration time camera.